THE LOCAL ORIGIN OF GLACIAL DRIFT

NORMAL till is made up predominantly of materials which have not been transported many miles, though some of the minor constituents have often come greater distances. Roughly speaking, the more distant the contributing rock formation, the less its contribution to the till at any given point. There are apparent exceptions to this generalization, but they are chiefly the result either of the unequal exposures of the several formations contributing to the drift, or to their unequal resistance to abrasion.

Locally, the constituents of the drift of distant origin, drop almost to zero. This is true both of drift composed chiefly of clay, and of that which contains abundant coarse material. In extreme cases, stony till is chiefly composed of blocks of rocks that have been moved but little from their original positions. They have been displaced and the clay or sand (the finer portions of the till) have been mixed with them, so that the two sorts of material appear to have been kneaded together. In such cases the rock masses are angular and rough, and frequently increase in size and number from the top of the till to its base. At the base they may be so abundant as to nearly exclude all other constituents. If the surface of the rock be much broken, and its uppermost layers disrupted and crumpled, as is sometimes the case, it may be difficult to say where the line between the bottom of the till and the surface of the underlying rock is to be drawn. Where the rock which gave origin to the drift was not well suited to making bowlders, the comminution of the material gave rise to clayey or earthy matter, as really though less obviously local in origin, as if it had remained in larger pieces. Considering the area of the continental ice-sheets, and the distance which much of the ice traveled, the small proportion of the drift which has come from distant

sources has always seemed a stumbling block to those who are familiar with the facts, but not with their meaning.

In Fig. 1, *a* represents the center of the sector of an ice-cap, and *b d* its circumference. The areas marked 1, 2, 3, and 4 represent successive and equally wide belts of rock of equal resistance and like topography. The center of movement is assumed to be at *a*. When the ice has advanced from *a* to *b d* the deposit of till made at that point is made by ice which, in so far as it has moved from the center, has passed over formations 1 to 4 in succession. In such situations the drift is normally found to contain more material from 4 than from 3, more from 3 than from 2, and more from 2 than from 1.

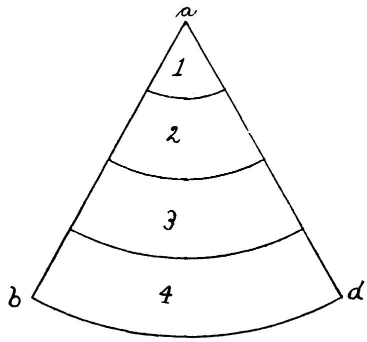

FIG. 1.

It will be understood that if the width of the exposures of the several formations were unequal, or if the several formations were of unequal resistance, the case might be very different. It is also clear that the topography of the several belts will influence the amounts of their contributions, and in view, first, of the varying widths of the various belts of rock passed over by the ice, second, of their varying topographies, and third, of their varying degrees of resistance, many exceptions may arise to the generalization that the contributions of various formations to the till of any locality are in inverse proportion to their distances from the point concerned.

The explanation of the markedly local character of the drift appears to involve several considerations. Fig. 1 illustrates one point involved. Suppose the ice passing over the formations 1, 2, 3, and 4, successively, gathers material with equal facility from each of them. By the time the ice from 1 has spread over 2, the average thickness of the basal layer of drift derived from 1, supposing none of it to have been deposited, would have been reduced to one third its original thickness, since the area of 2 is

three times as great as that of 1. By the time the same ice has spread over 3, the basal layer of drift derived from 1 will have been reduced to one fifth its original thickness, since the area of 3 is five times the area of 1. Still supposing none of it to have been deposited when 4 has been overspread, the thickness of the drift derived from 1 when the ice has covered 4, will be but one seventh of that which it possessed over 1. Even supposing all the drift from 1 to be carried to 4 over the intervening areas, it is thus seen that at such a point as *c*, the amount of distant material should be relatively small. If the ice keeps an equal amount of drift in and beneath itself by gathering enough new material to counterbalance the thinning of that previously held, the till at *c* should be made up as follows:

From formation 1 - - - - - - - -	$\frac{1}{16}$
From formation 2 - - - - - - -	$\frac{3}{16}$
From formation 3 - - - - - - - -	$\frac{5}{16}$
From formation 4 - - - - - - -	$\frac{7}{16}$

Thus the spread of the ice will tend constantly to decrease the proportion of basal drift derived from any formation, once that formation is passed.

Since some of the drift derived from 1 would doubtless be lodged as the ice advanced over formation 2, the average thickness of that carried from 1 to 3 will be correspondingly diminished beyond the figure given ($\frac{1}{5}$ of that over 1). Since more of the material from 1 will in all probability be deposited on 3, as the ice advances to 4, the figures given for the thickness on 4 of drift derived from 1 ($\frac{1}{7}$ of that on 1), will need to be still further reduced, and that by a larger amount than that to which the $\frac{1}{5}$ was subject. In view of the continual lodgment of drift, it will be seen that the series of fractions given above, namely $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$, and $\frac{7}{16}$ will need to be changed by some undetermined amount, but so that the extremes well be farther apart, and the differences between successive members greater. If $\frac{3}{4}$ of the drift carried from 1, were deposited on 2, 3, and 4, and $\frac{1}{2}$ of that from 2 on 3 and 4, and $\frac{1}{4}$ of that from 3 on 4, the last member of the preceding series of fractions would be increased at the

expense of others. The preceding series would then be brought to some such terms as the following:

From formation 1	- - - - -	$\frac{1}{64} = 1\frac{1}{2}$ % +
From formation 2	- - - - -	$\frac{4}{64} = 6$ % +
From formation 3	- - - - -	$\frac{15}{64} = 23$ % +
From formation 4	- - - - -	$\frac{44}{64} = 69$ % +

Thus the constant tendency of the drift to lodge, after being once started, tends still further to diminish the quantity of drift from any formation after the formation is passed.

The effectiveness of the tendency to lodgment of drift near its source is dependent on several conditions. One of them is the rate and steadiness of movement, and another the topography of the surface. The edge of the ice is not believed to have moved forward at equal rates, either during its advance or during its retreat. Whenever the edge of the ice, after a given advance, remained approximately constant in position for a period of years, all the drift brought to the edge of the ice during the halt accumulates beneath it. It presently accumulates in sufficient quantity to form a submarginal ridge or barrier, and when the ice is again affected by movement sufficient to carry its edge farther forward, it is obliged to override or carry forward this submarginal accumulation. Judging from the phenomena of North Greenland, such material was more largely overriden than urged along. Thus the drift gathered toward the center of the ice field is lodged in exceptional quantity wherever the edge of the ice was for a time nearly stationary, and the ice which passed on over the drift which was lodged proceeded to gather a new load made up chiefly of material derived from the surface outside the position of the preceding halt. This tends to emphasize the local facies of the drift.

These considerations in themselves would be quite sufficient, as the last set of fractions shows, to explain the great predominance of relatively local material in the drift of any given region, but other factors serve to emphasize the point still further.

The top of the ice-sheet moves forward faster than the bottom. One reason for this is that the lower part, which is more

fully charged with débris, becomes more rigid, while the more mobile part above moves on over it. If in Fig. 2 the several curves *a*, *b*, *c*, *d* represent the profiles of the ice in successive stages of advance, the ice which is at the bottom, and which is eroding formation 4, may not be the ice which was at the bottom over 2, but instead ice which was well up from the bottom over this formation. In this case it is clear that the ice working on 4 has relatively little material derived from 2. At first thought it might seem that it should have nothing, but this conclusion does not follow. As the relatively débris-free ice above moves

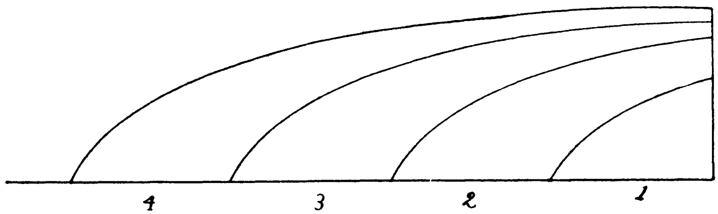

FIG. 2.

over the relatively heavily débris-charged ice below, it drags along some of the material lying in the upper part of the débris zone. Thus as the ice moves over 4, the upper part, being in faster motion, will be carrying along some of that derived from 2 and and even from 1, so that at least a small amount of the material from these formations is to be expected in the bottom of the ice over 4. Nevertheless, the tendency is all along to leave the material already carried by the ice in the rear, and to let the advancing edge acquire its own load, primarily from the successive formations invaded. The result of differential movement, the faster movement being above, is to diminish still further the proportion of the material in the drift at any given point which was derived from distant sources. Because of the effects of differential movement therefore, the last series of fractions would need to be still further changed, so that the first member would be smaller and the last larger.

The topography over which the ice had moved would also influence the proportions of material of near and distant origin.

If the ice passing over 2 encounters a rough topography, so that drift was introduced into the ice far above its base, a large amount of matter from 2 would go forward in the more rapidly moving upper part, and be found in the ice, and finally in the drift, over 4, or beyond.

There is at least one other factor involved. Much of the ice which passes over 4 (Fig. 2) never passed over 1, but accumulated on 2, 3, and 4. This does not preclude the passage of some ice from 1 to 4, but simply means that much of the ice at 4 has never had a chance to work on 1. The idea involved may be gathered from Fig. 3. Let the lines *a*, *b*, and

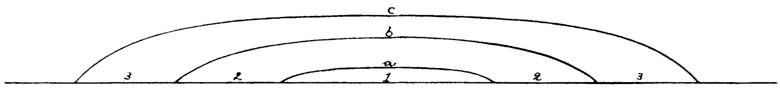

FIG. 3.

c, respectively, represent the successive profiles of a growing ice-sheet. Much of the upper part of the ice, the profile, of which is *c*, accumulated over areas 2 and 3 and did not come from 1, as already stated. This upper ice which never worked on 1, is moving more rapidly than the ice at lower levels which came in part from 1. Furthermore the conditions of snowfall and movement are such as to develop a high marginal and a low central gradient. The excessive marginal snowfall, for such was probably the condition, will in some sense check movement from the center, and make the marginal portion of the field the effective dynamic center of movement. The origin of much of the ice far from the center of the ice-sheet, where it had no chance to work on rock formations near the center, tended still further to make the material carried and deposited by the ice at any point of local origin. The effect of this factor is to still further differentiate the fractions of the preceding series.

When the spread of the ice, the constant tendency to lodgment of drift in transit, the differential movement, and the marginal origin of much of the ice are all considered, it is probably true that the fractions given on pp. 428, 429 give much

too large a percentage of widely transported material in the drift occupying such a position as that to which the fractions are applied. Taken together, too, these factors would seem to explain adequately the local character of the material of the till.

R. D. S.